

# **Low Temperature Life-Cycle Testing of a Lithium-Ion Battery for Low-Earth-Orbiting Spacecraft**

Concha Reid  
NASA Glenn Research Center  
21000 Brookpark Road  
MS 309-1  
Cleveland, OH 44135

A flight-qualified, lithium-ion (Li-ion) battery developed for the Mars Surveyor Program 2001 lander is undergoing life-testing at low temperature under a low-Earth-orbit (LEO) profile to assess its capability to provide long term energy storage for aerospace missions. NASA has embarked upon an ambitious course to return humans to the moon by 2015-2020 in preparation for robotic and human exploration of Mars and robotic exploration of the moons of outer planets. Li-ion batteries are excellent candidates to provide power and energy storage for multiple aspects of these missions due to their low specific energy, low energy density, and excellent low temperature performance. Laboratory testing of Li-ion technology is necessary in order to assess lifetime, characterize multi-cell battery-level performance under aerospace conditions, and to gauge safety aspects of the technology. Life-cycle testing provides an opportunity to examine battery-level performance and the dynamics of individual cells in the stack over the entire life of the battery. Data generated through this testing will be critical to establish confidence in the technology for its widespread use in manned and unmanned missions.

This paper discusses the performance of the 28 volt, 25 ampere-hour battery through 6000 LEO cycles, which corresponds to one year on LEO orbit. Testing is being performed at 0 °C and 40% depth-of-discharge. Individual cell behaviors and their effect on the performance of the battery are described. Capacity, impedance, energy efficiency and end-of-discharge voltage at 1000 cycle intervals are reported. Results from this life-testing will help contribute to the database on battery-level performance of aerospace Li-ion batteries and low temperature cycling under LEO conditions.

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CLEVELAND, OHIO

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**Huntsville, AL**

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## **Background**

- Life cycle data of lithium-ion cell chemistry is critical to continue to establish life and validate technology for flight programs
- Battery level testing is required in addition to individual cell level testing
- The test battery was designed, built and flight-qualified for the Mars 2001 Surveyor Program Lander
- The current NASA goal for lithium-ion technology for LEO is 30,000 cycles, the equivalent of about five years on orbit
- 5 flight-qualified batteries became available for testing after the cancellation of the flight program
- Provided a unique opportunity to perform laboratory life-cycle testing on flight hardware

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## Background (cont.)

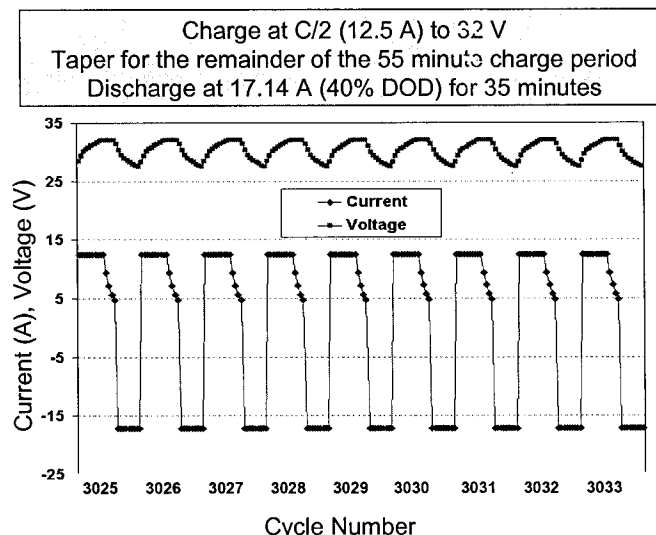
- Battery Characteristics
  - Lithium-Ion Chemistry
  - 25 ampere-hours
  - 28 Volts
  - 8 Cells
- Four test organizations
  - GRC – LEO testing at 0 °C
  - JPL – LEO testing at 20 °C, Mission Simulation testing
  - AFRL - LEO testing at 23 °C
  - NRL – GEO testing

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## LEO Cycling at 0 °C



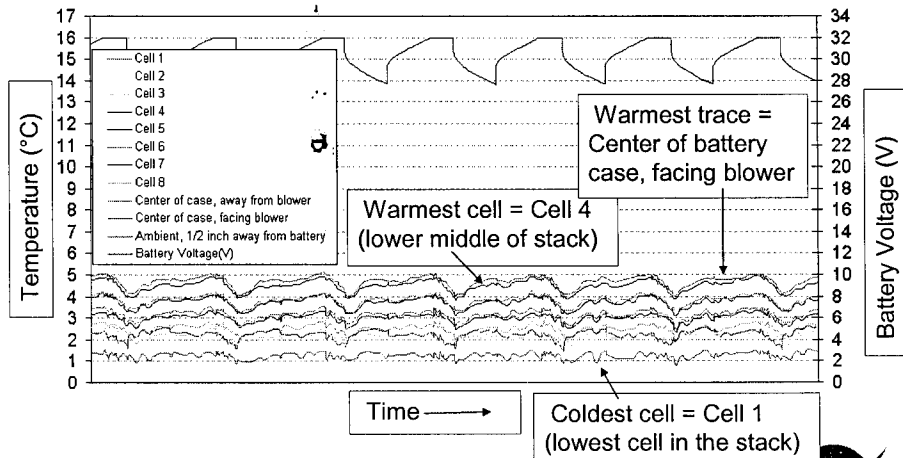
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## Temperature Profile during LEO Cycling

Chamber is set at 0 °C

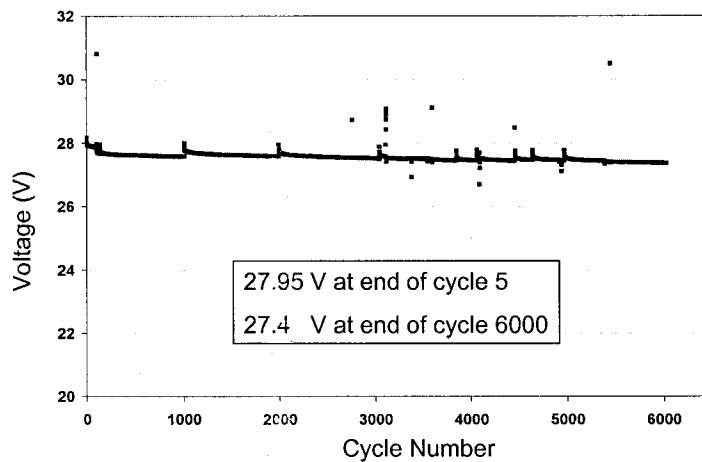


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## End-of-Discharge Voltage

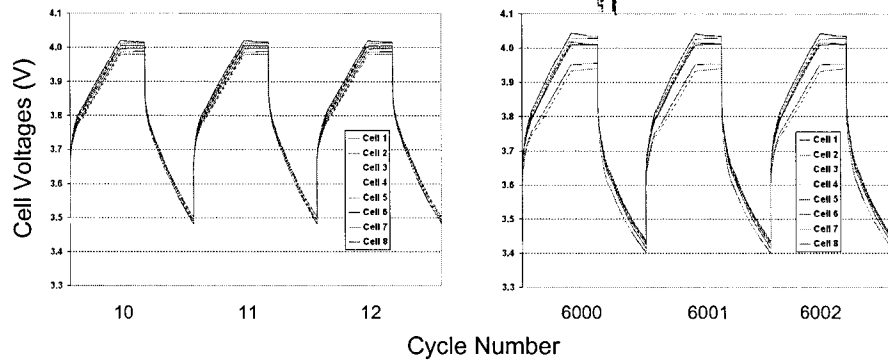


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## Cell Voltages During LEO Cycling

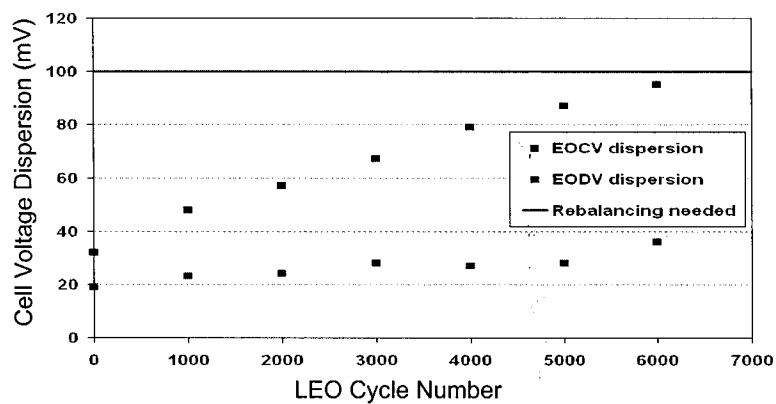


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## Cell Voltage Dispersion Trends

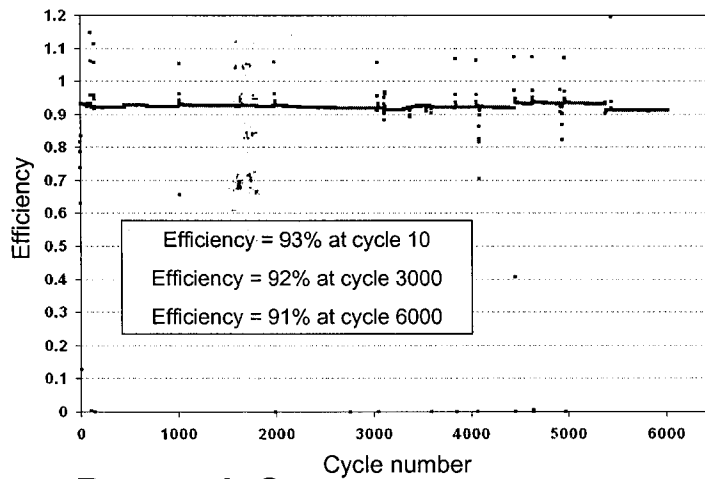


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### Energy Efficiency (during LEO cycling at 40% DOD)

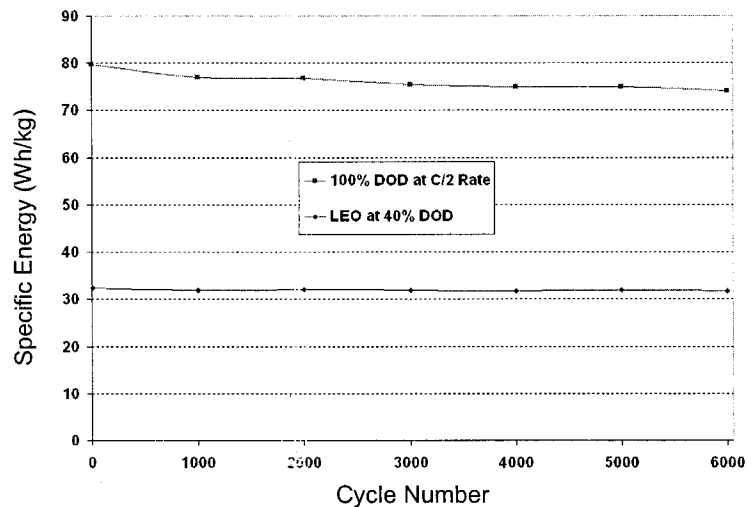


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### Specific Energy at 40% and 100% DOD



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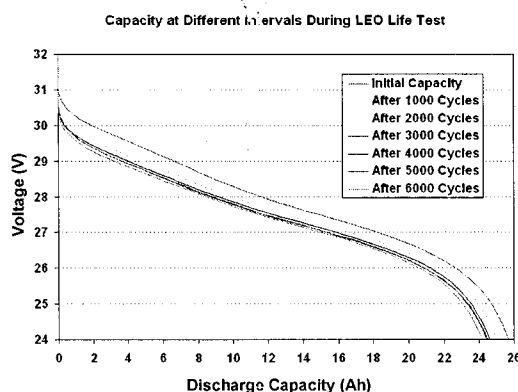
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## 100% DOD Capacity Test Results at 0 °C

- Charge at C/2 to 32 V or until the first cell reaches 4.05V, allow current to taper to C/50
- Discharge at 0.7C (40% DOD rate) to 24.0 V or until the 1st cell reaches 2.5 V

Interval (after X cycles)	Capacity (Ah)	% of Initial Capacity
Initial	25.7	100
1000	25.0	97
2000	24.9	97
3000	24.6	96
4000	24.5	95
5000	24.5	95
6000	24.2	94

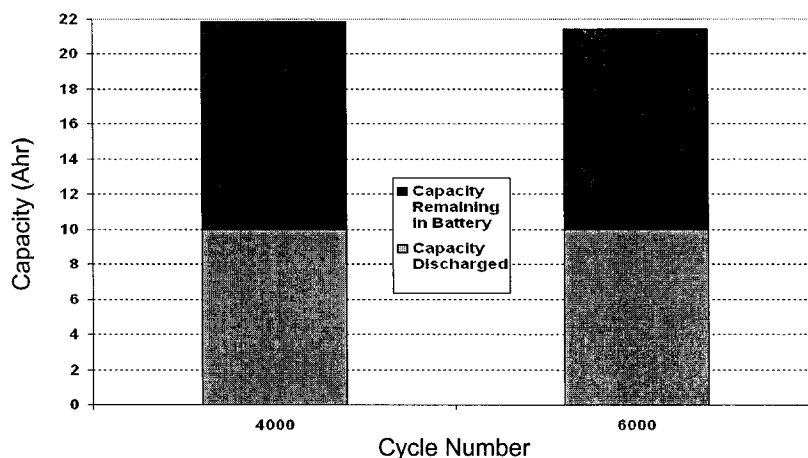


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## Capacity Remaining in Battery after LEO Cycling

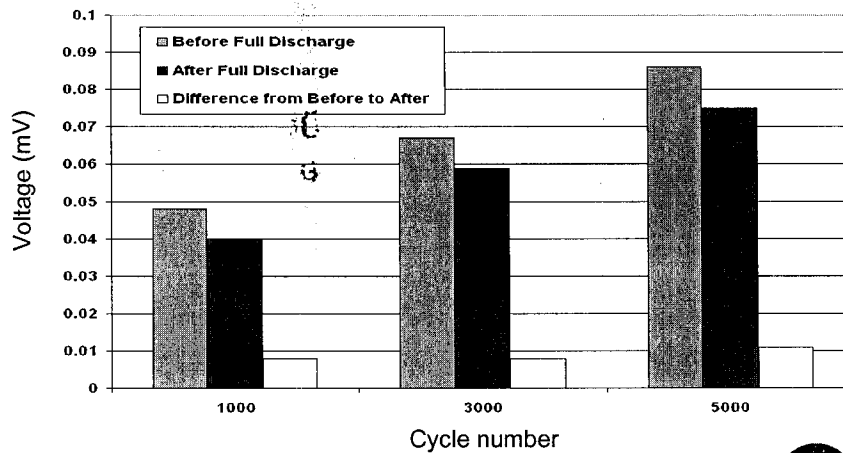


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## Effect of Capacity Checks on Cell Voltage Dispersion on Charge

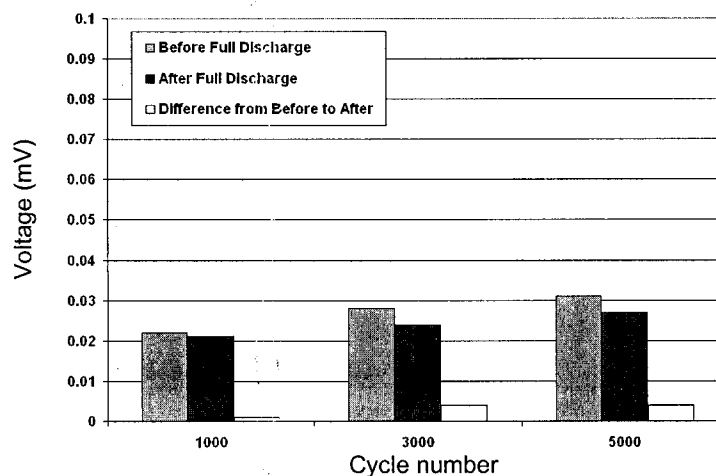


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## Effect of Capacity Checks on Cell Voltage Dispersion on Discharge



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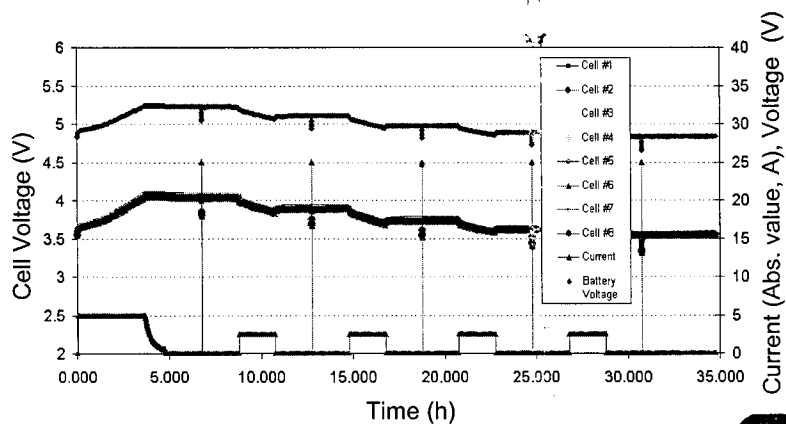
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## Current-Interrupt Impedance Test at 0 °C

Charged at 5 A (C/5) to 32.4 V, Discharged at 25 A for 10 seconds  
 Rested 2 hours before and after each pulse  
 Discharged at 2.5 A for 2 hours (removed 5 Ah) between pulses

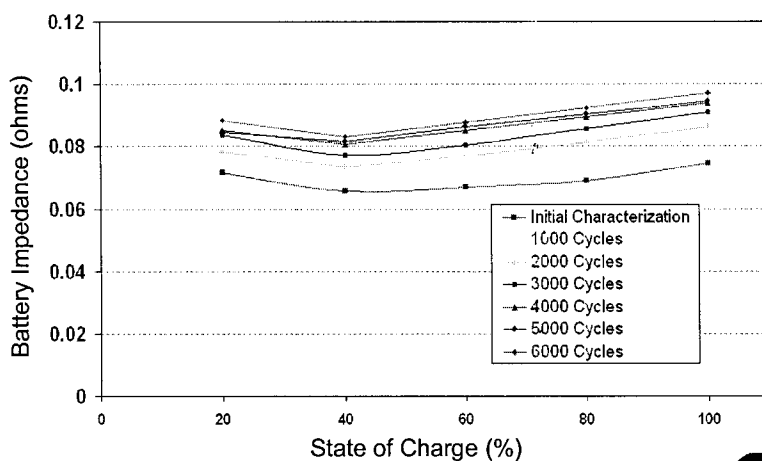


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## Battery Impedance at 0 °C at Different Intervals (calculated 1 hour after pulse)

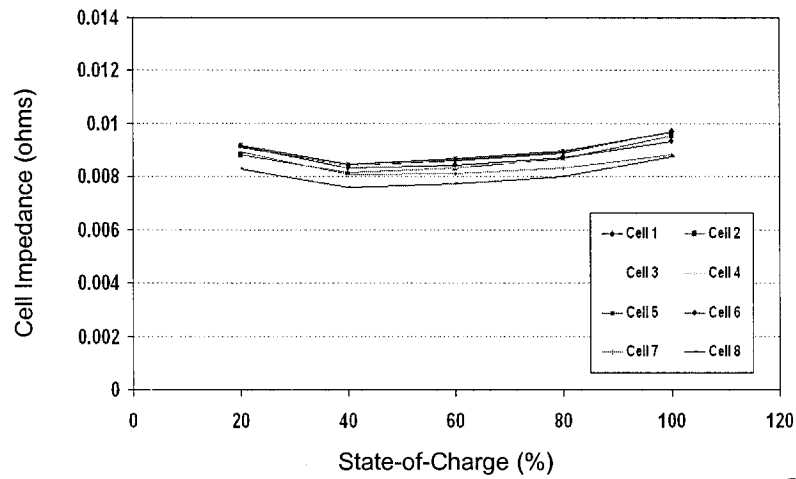


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### Initial Cell Impedances at 0 °C (calculated 1 hour after pulse)

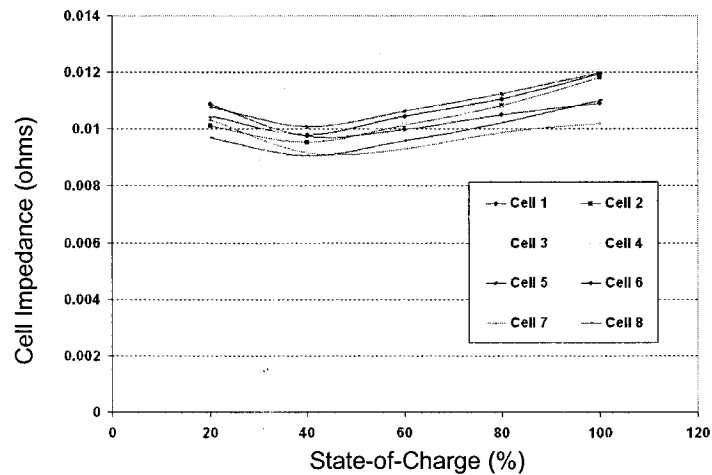


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### Cell Impedances at 0 °C after 6000 Cycles (calculated 1 hour after pulse)

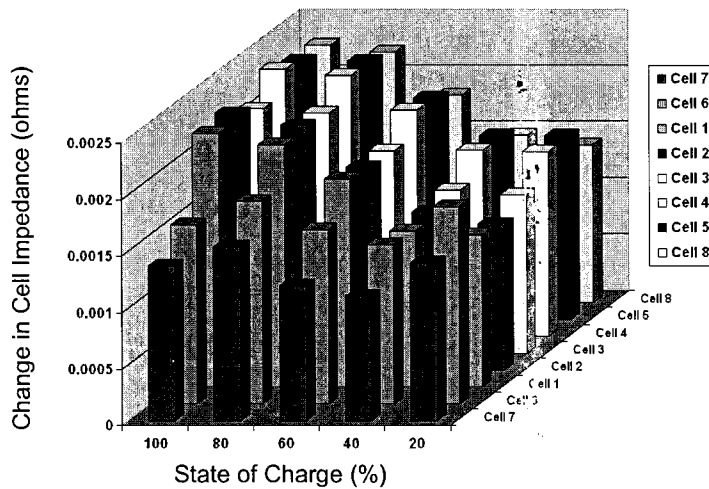


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## Change in Cell Impedance from Initial Characterization to 6000 Cycles



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## Conclusions

- Battery has delivered greater than 6000 cycles (equivalent to over 1 year in low-Earth-orbit).
- Battery delivered 94% of the initial capacity after 6000 cycles (measured using 100% DOD at 0 °C).
- Through 6000 cycles, cell voltage dispersion measured 95 mV on charge and 36 mV on discharge. Cell balancing is projected to be necessary after 7000 cycles.
- The battery end-of-discharge voltage decreased 550 mV over 6000 cycles.

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## **Future Testing**

- LEO cycling at 40% DOD at 0 °C will continue.
- Capacity at 100% DOD will be measured at 0 °C every 1000 cycles.
- Current interrupt-impedance tests at 0 °C will be repeated every 1000 cycles. Changes in impedances as a function of cycle life will be observed.
- Cells will be rebalanced when cell voltage dispersion exceeds 100 mV on charge and 80 mV on discharge.

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